Plans for Extreme Energy Cosmic Ray Observations from Space

Presented for the EUSO Consortium by Jim Adams

- **Background**
  - o **Previous Experiments**
  - o **Present Experiments**
- **EUSO**
  - o **The Instrument**
  - o **Science Goals**
- **Planned Investigations**
  - o **Spectral Models**
  - o **Possible Sources**
  - o **New Physics**
- **The Next Generation (OWL)**
- **Conclusions**

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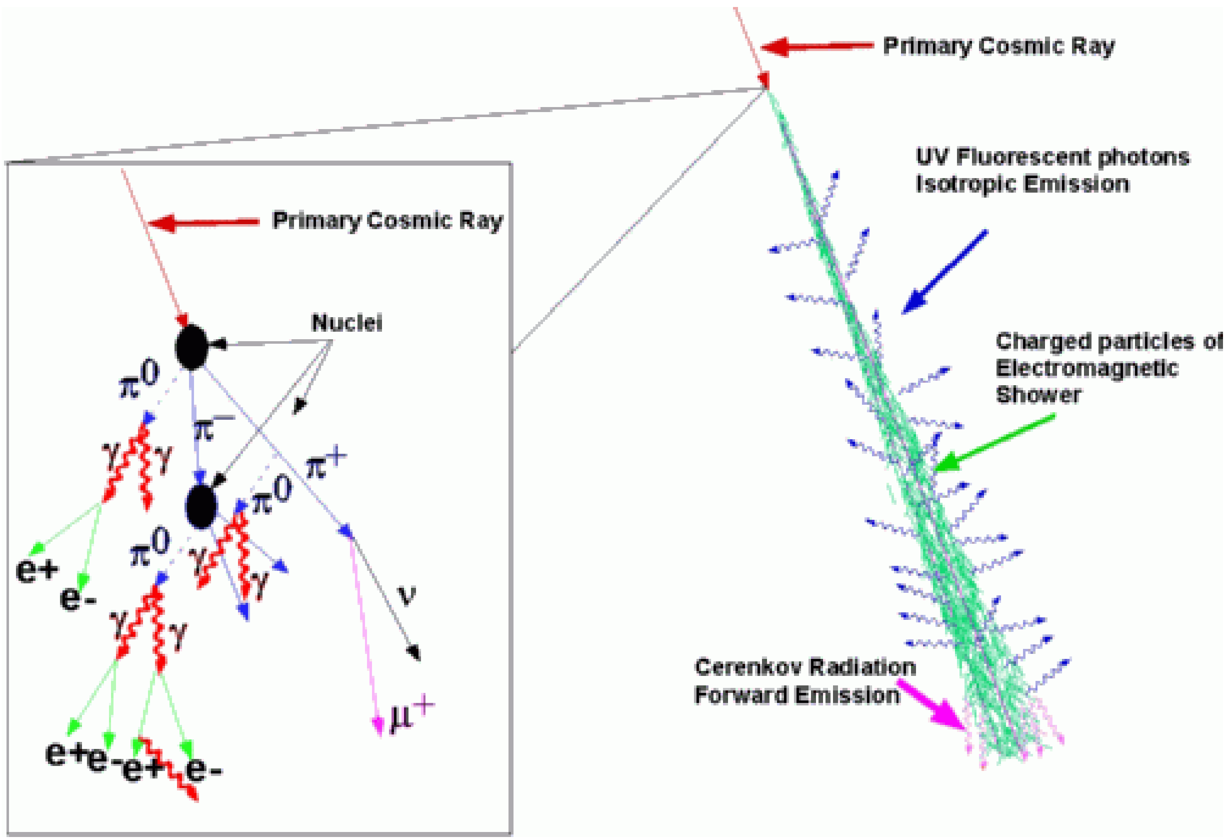
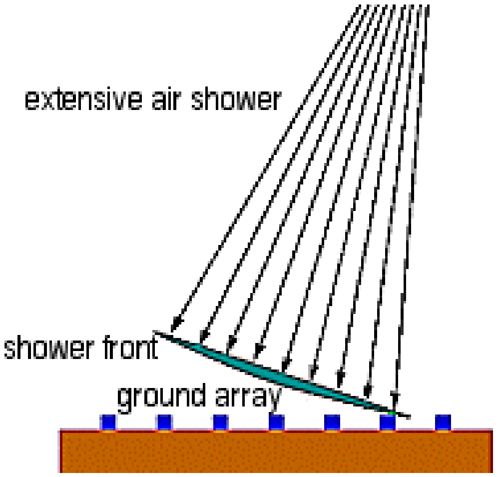
Background

- How it works:





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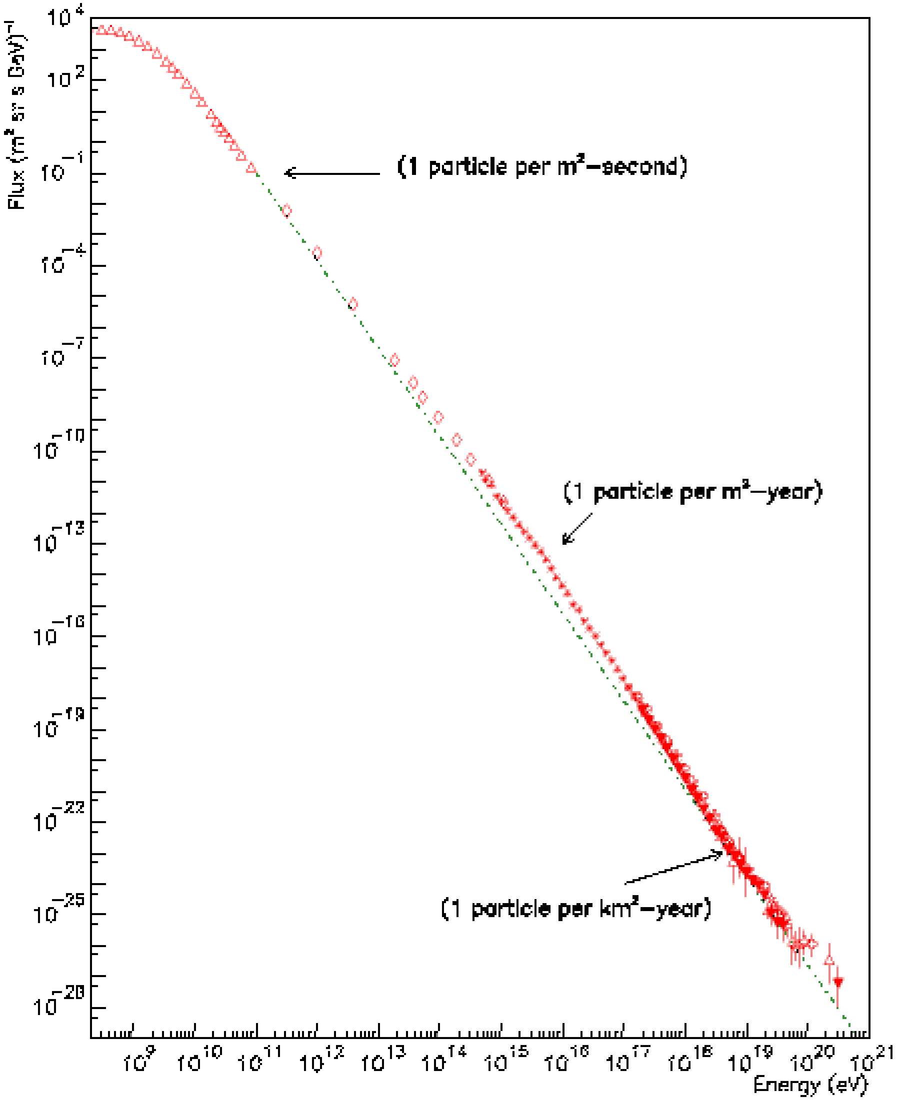


Background

- Greisen-Zatsepin-Kuz'min (GZK) Cutoff (~$5X10^{19}$ eV)
  - Photopion Production on the Cosmic Microwave Background

$$P + h\upsilon \rightarrow N + \pi^{+}$$

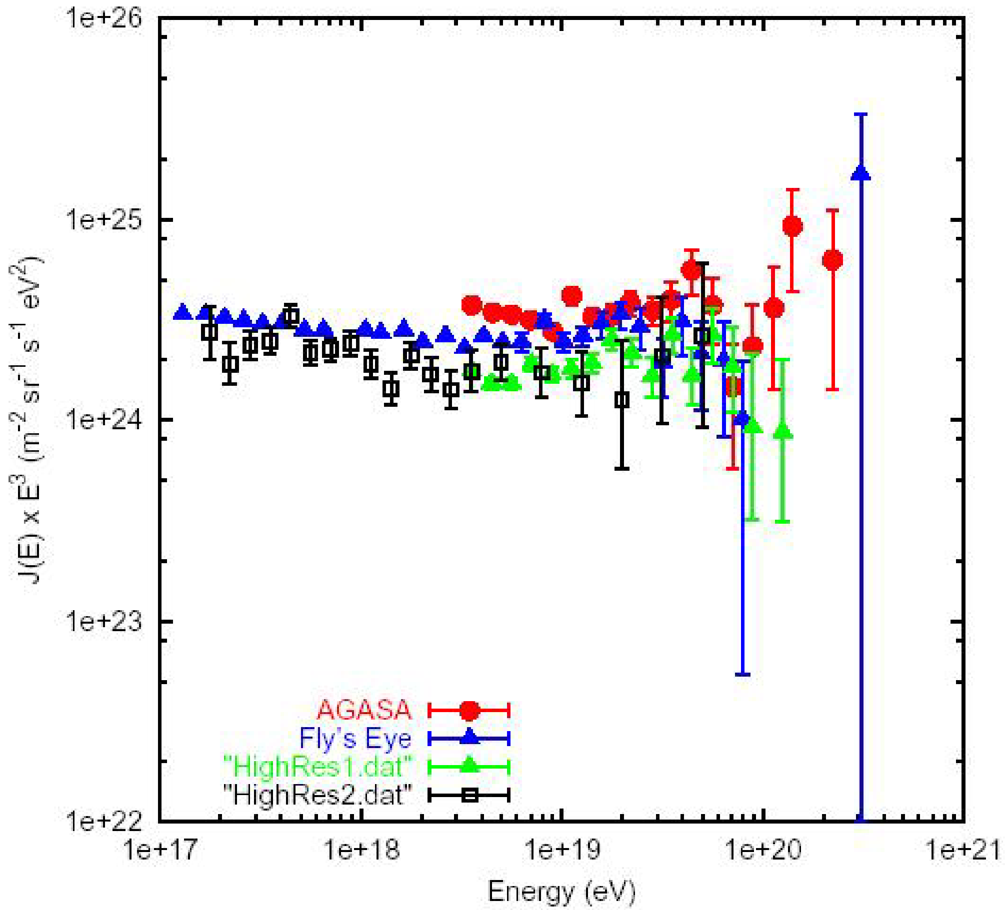
$$P + h\upsilon \rightarrow P + \pi^{+} + \pi^{-}$$

$$P + h\upsilon \rightarrow P + \pi^{0}$$

- Nuclear Photodisintegration (~$2X10^{20}$ eV)
  - On the Cosmic Microwave Background
  - On the Cosmic Infrared Background
- On the 15th of October, 1991 the Fly's Eye experiment recorded an event with $3.2X10^{20}$ eV!
  - Every experiment since with enough collecting power to do so has recorded events with $E > 10^{20}$ eV

Past Experiments

- Fly's Eye, AGASA, HiRes1 and HiRes2

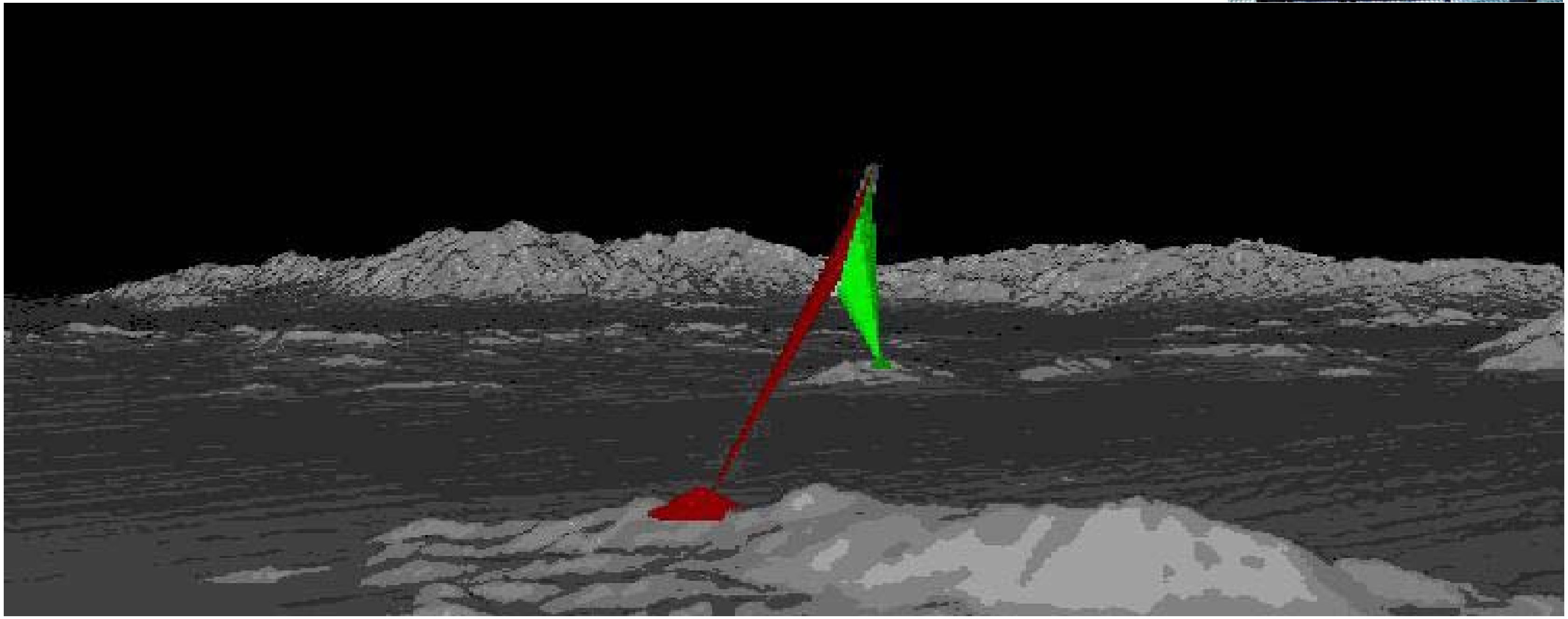


Plans for Extreme Energy Cosmic Ray Observations from Space

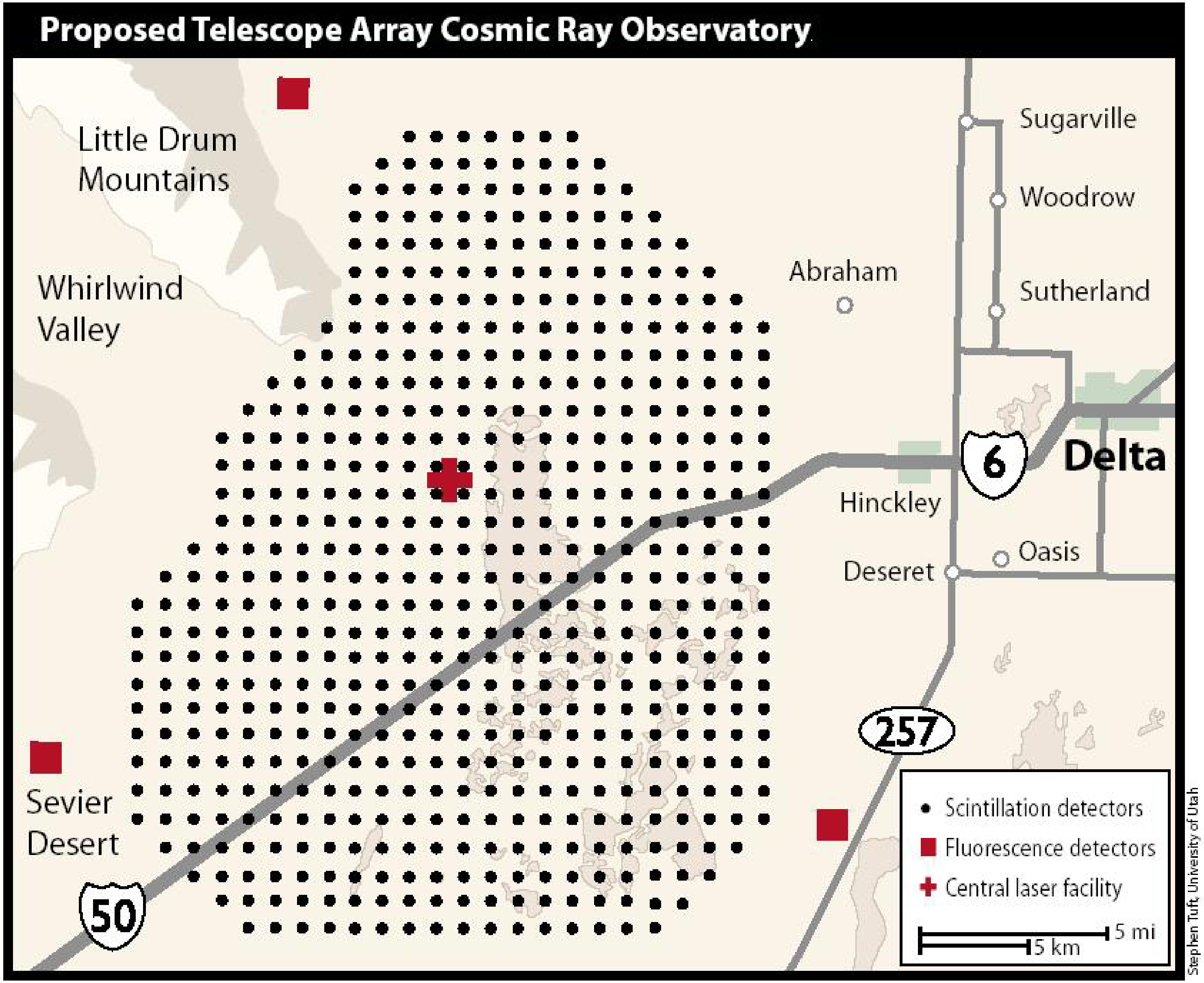
Present Experiments

- **Stereo HiRes**

Dugway Proving Ground, Utah



Plans for Extreme Energy Cosmic Ray Observations from Space



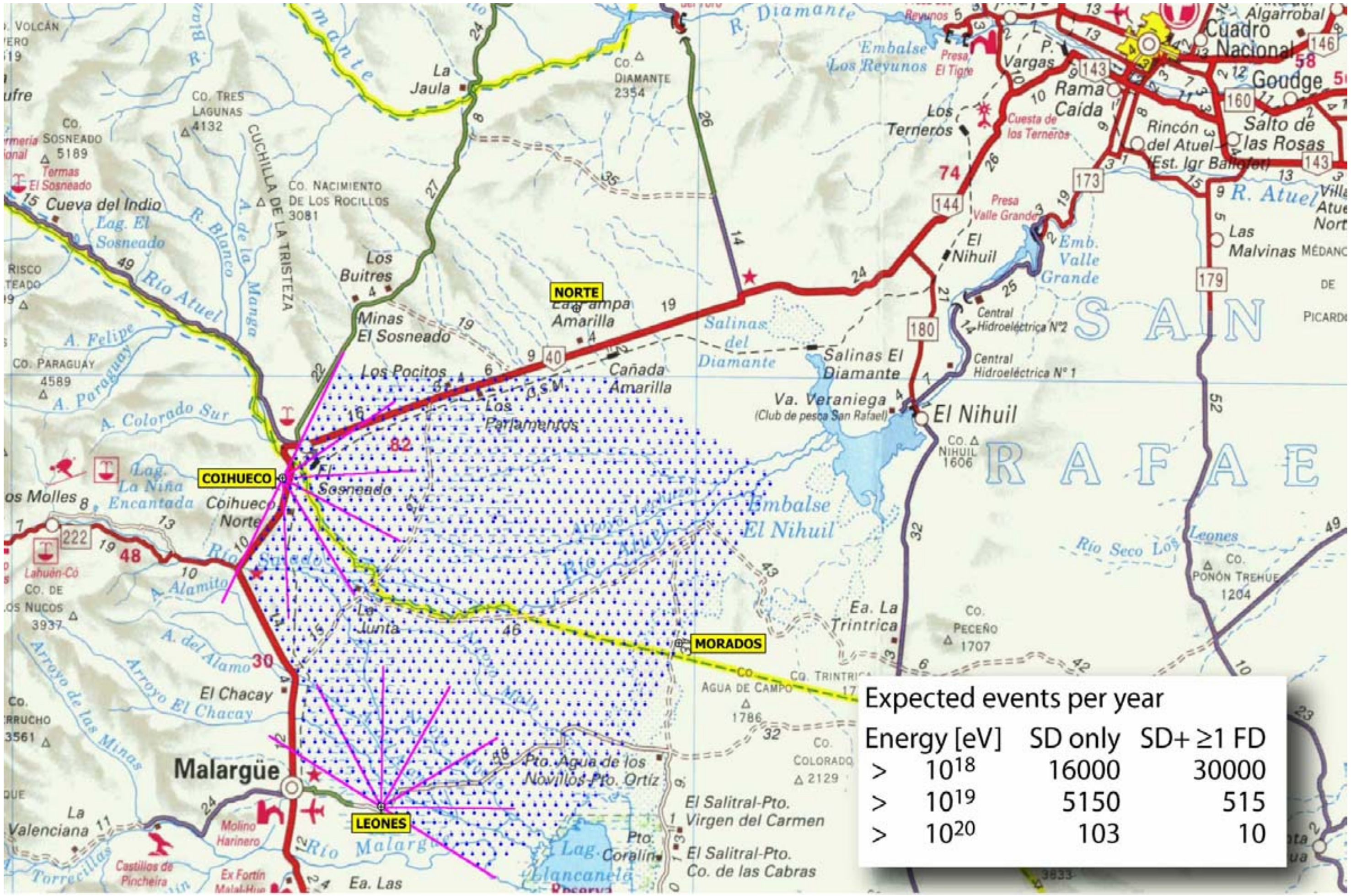
Plans for Extreme Energy Cosmic Ray Observations from Space

PIERRE AUGER OBSERVATORY

First concepts	1991
Ground breaking Malargue	March 1999
First events	2000
Prototype running	2001-
Production (300 tanks by Jan-04)	now
Full Southern Site	2005
Start Northern Site	2006
Full-sky Pierre Auger Observatory	2010++

Plans for Extreme Energy Cosmic Ray Observations from Space

1600 water Cherenkov detectors with 1.5 km spacing on 3000 km^2
4 stations with 24 fluorescence telescopes



Expected events per year

Energy [eV]	SD only	SD+ ≥1 FD
> 10^{18}	16000	30000
> 10^{19}	5150	515
> 10^{20}	103	10

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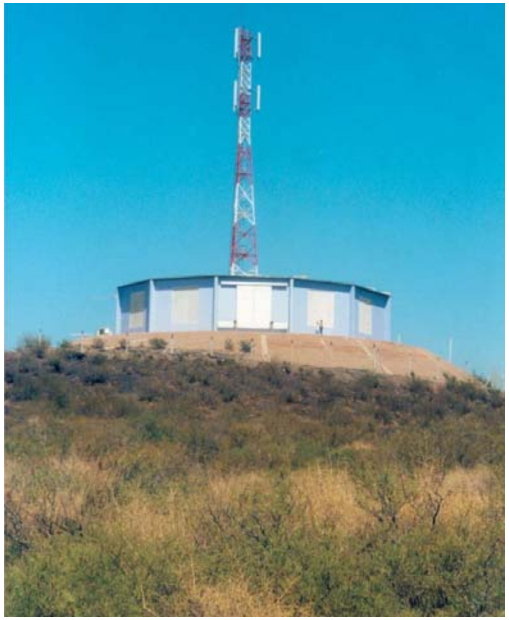
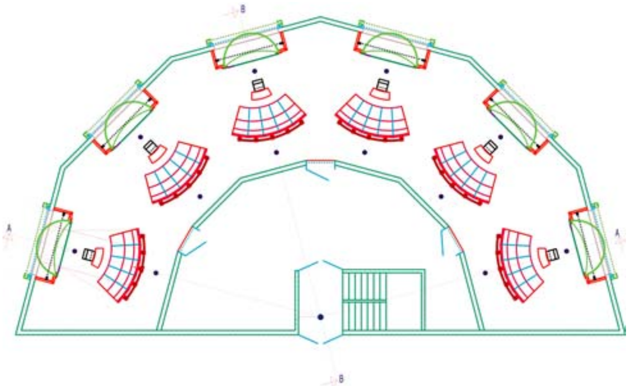
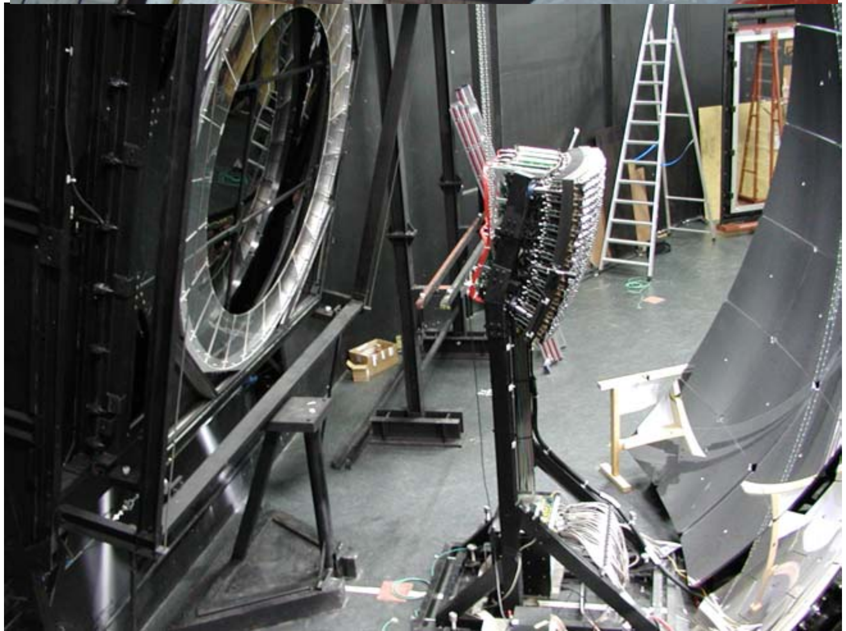
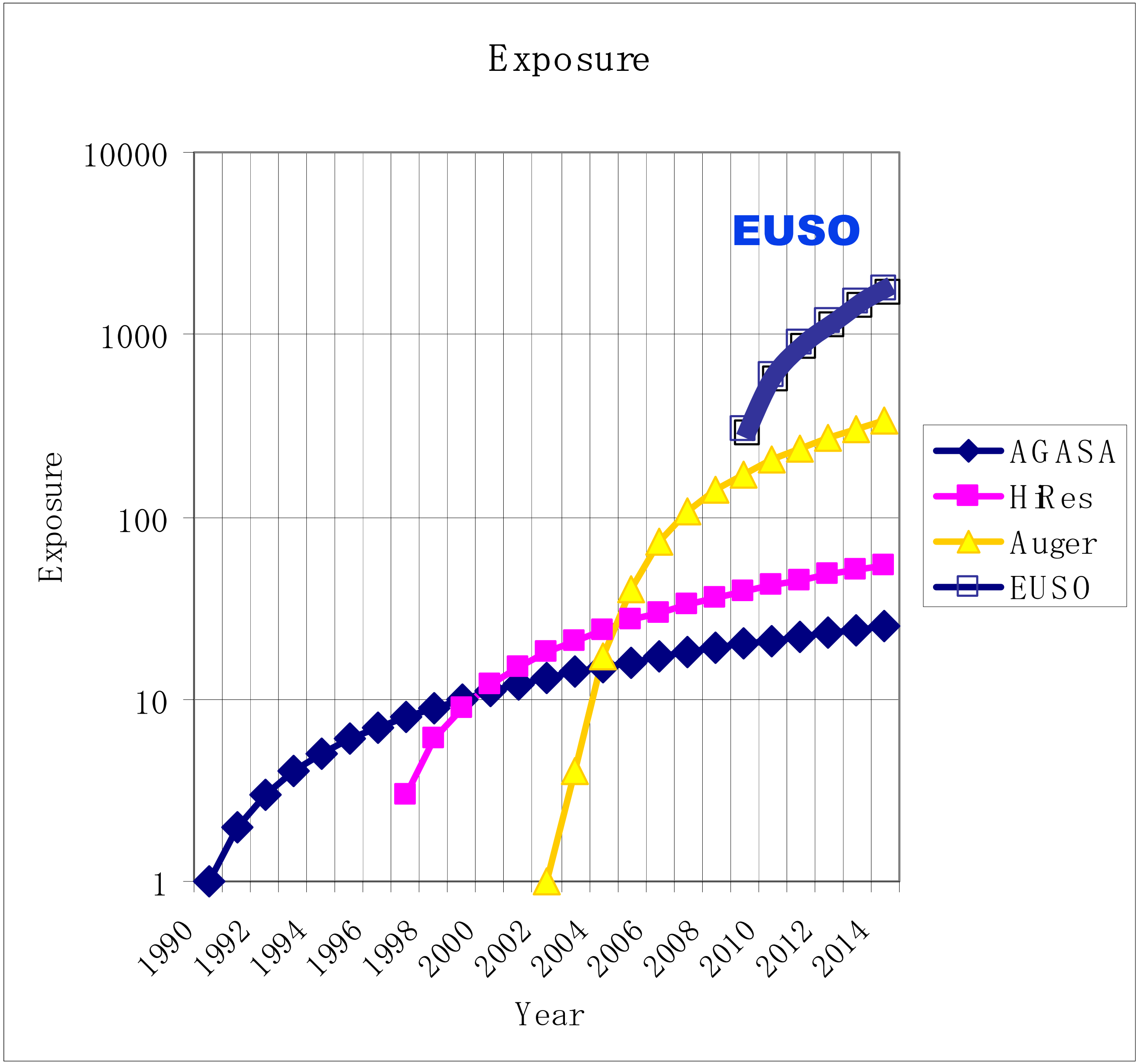






Exposure Factor



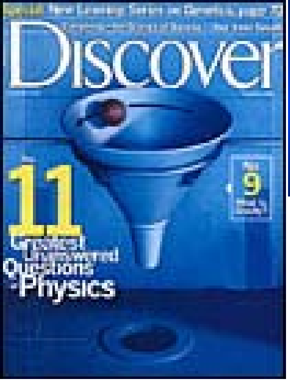
Extreme Universe Space Observatory

An ESA Mission to investigate Extreme Energy Cosmic Rays

>120 Scientists

40 Laboratories

France, Germany, Italy, Japan, Portugal, Spain, Switzerland and the US



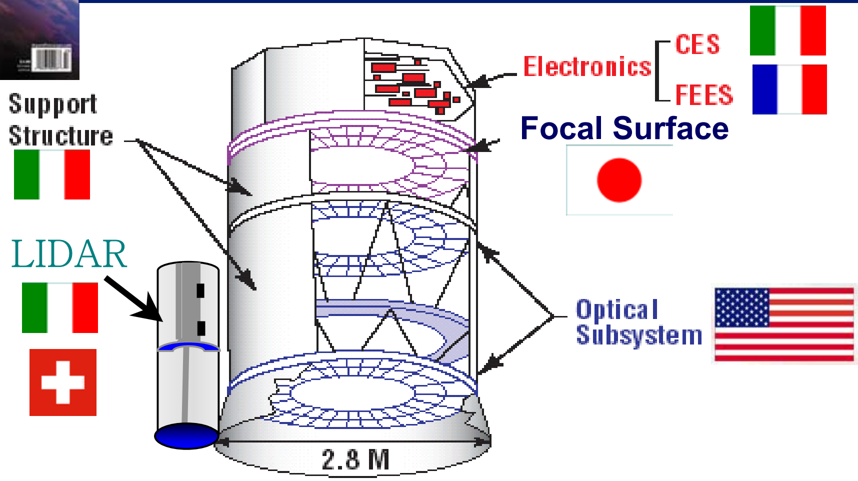
Scientific Goals

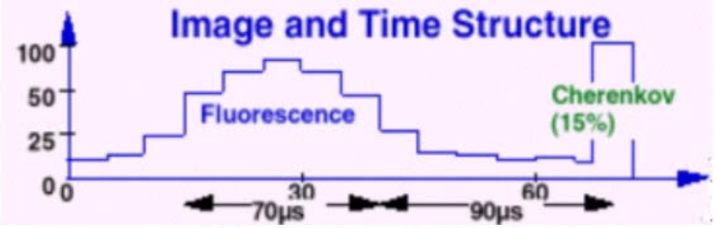
Science Driver:

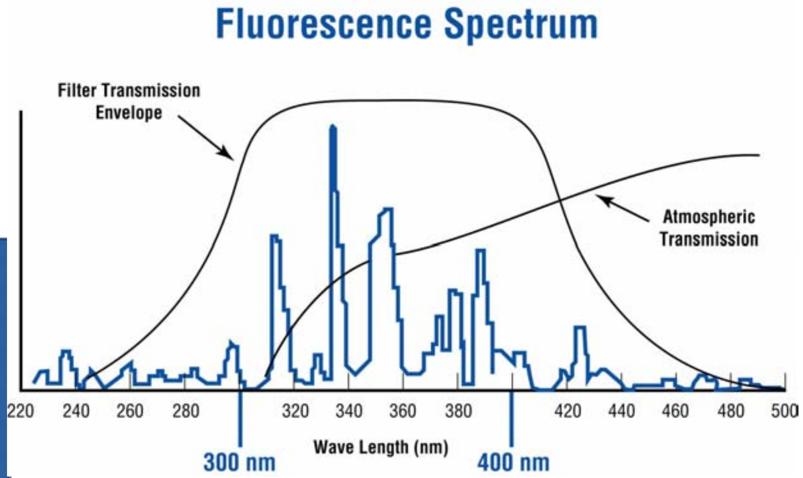
Question 5: Where do ultrahigh-energy particles come from?

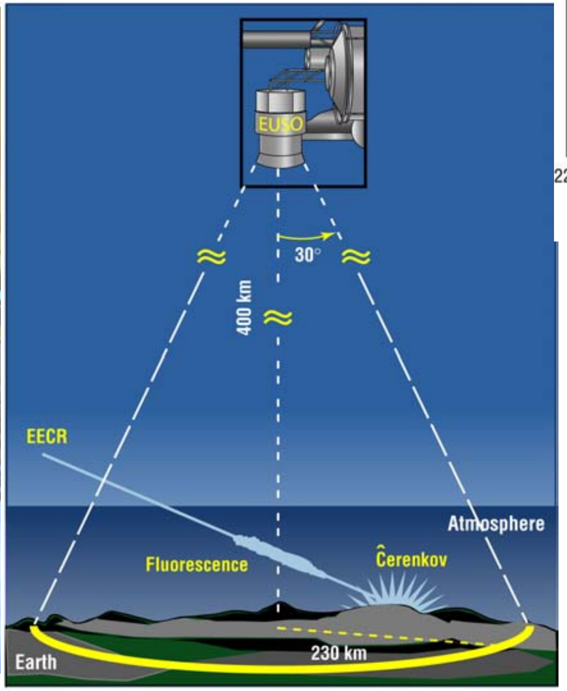
- Investigation of the highest energy processes present and accessible in the Universe through the detection and analysis of the Extreme Energy Component of the Cosmic Radiation (i.e. particles with energies > 5×10^{19} eV where protons loose energy by pion production on the microwave background, i.e. the GZK cutoff).
- Open the Channel of High Energy Neutrino Astronomy to probe the boundaries of the Extreme Universe and to investigate the nature and distribution of the EECR sources.

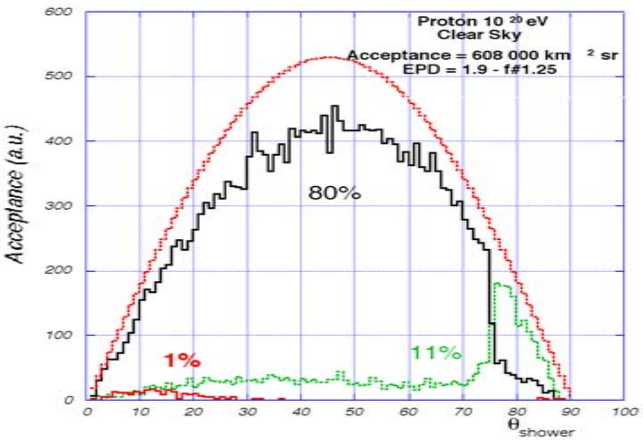
EUSO Instrument







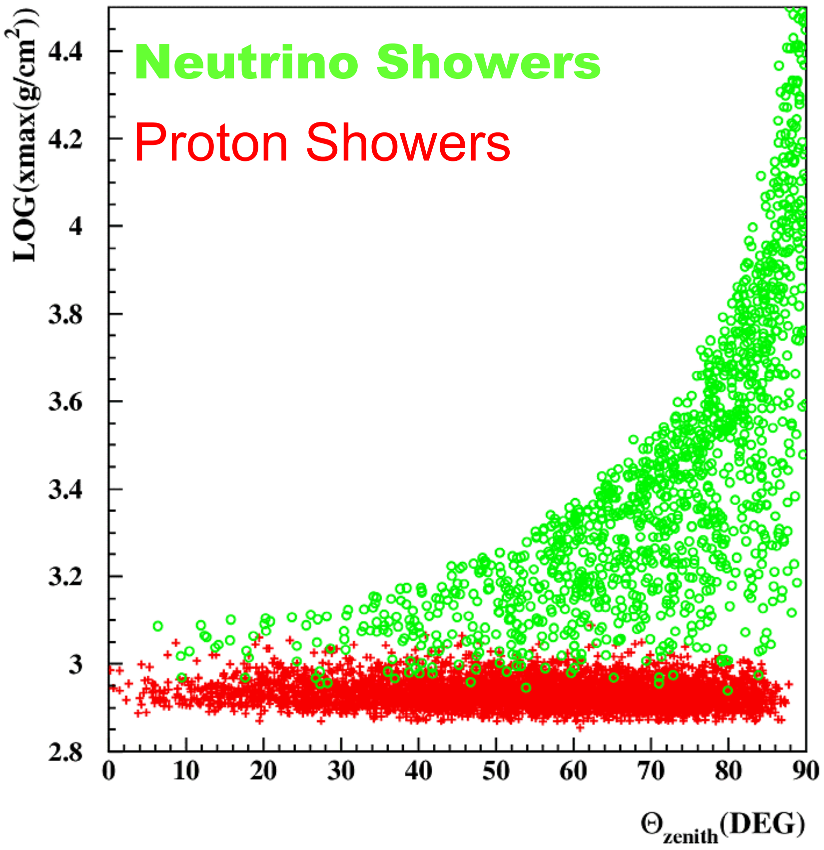




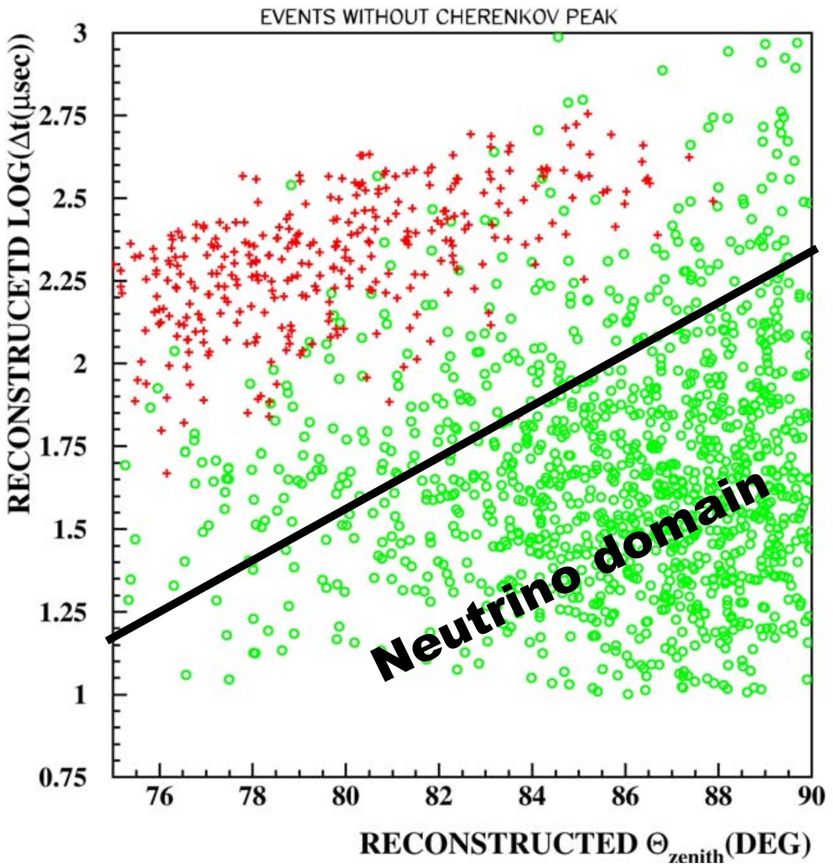
Neutrino Detection Capability

Just using observables
No need for Cherenkov ref.

Zenith Angle vs. Xmax



Zenith Angle vs. Shower Time width

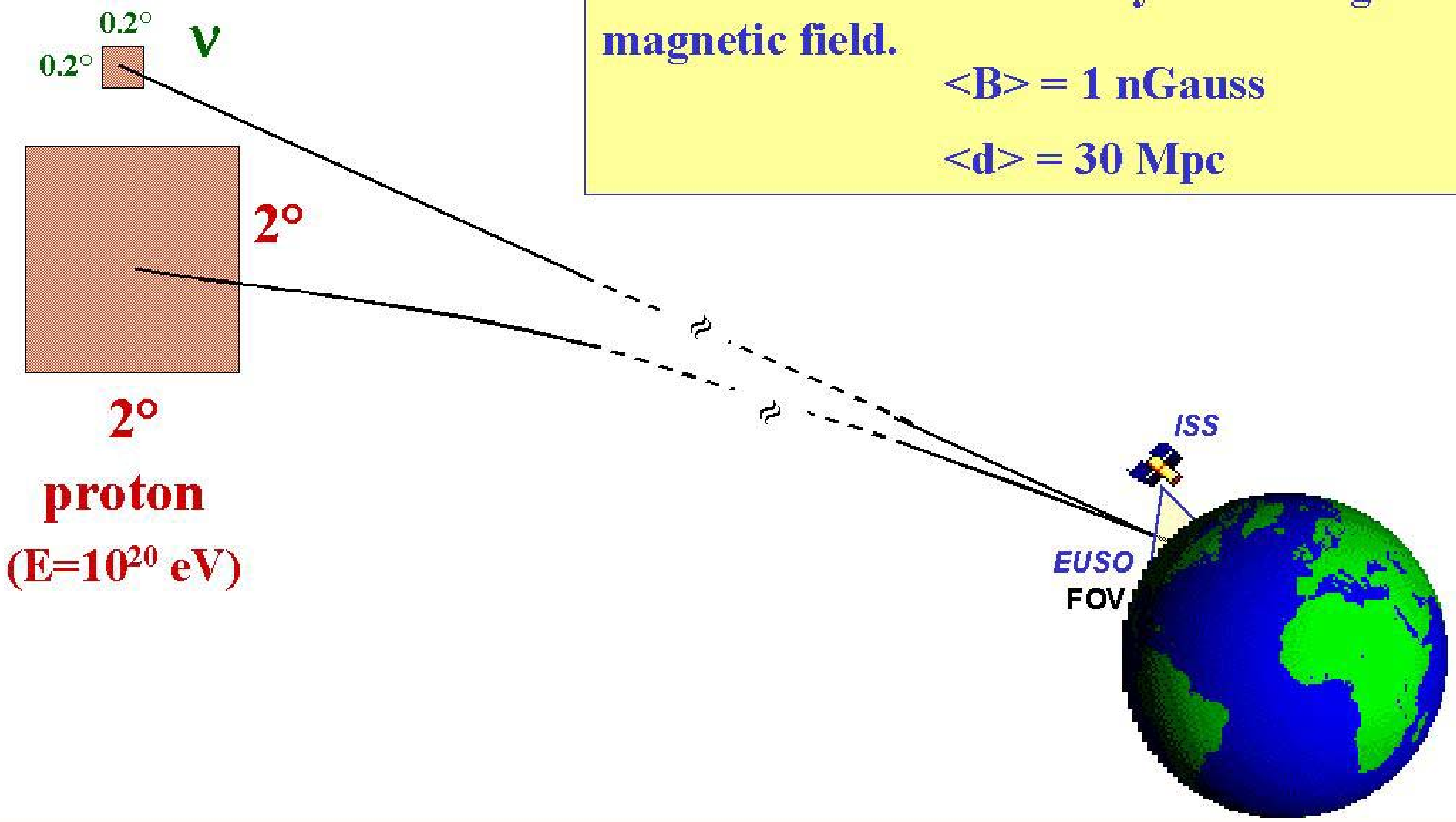


Astronomy at Extreme Energies

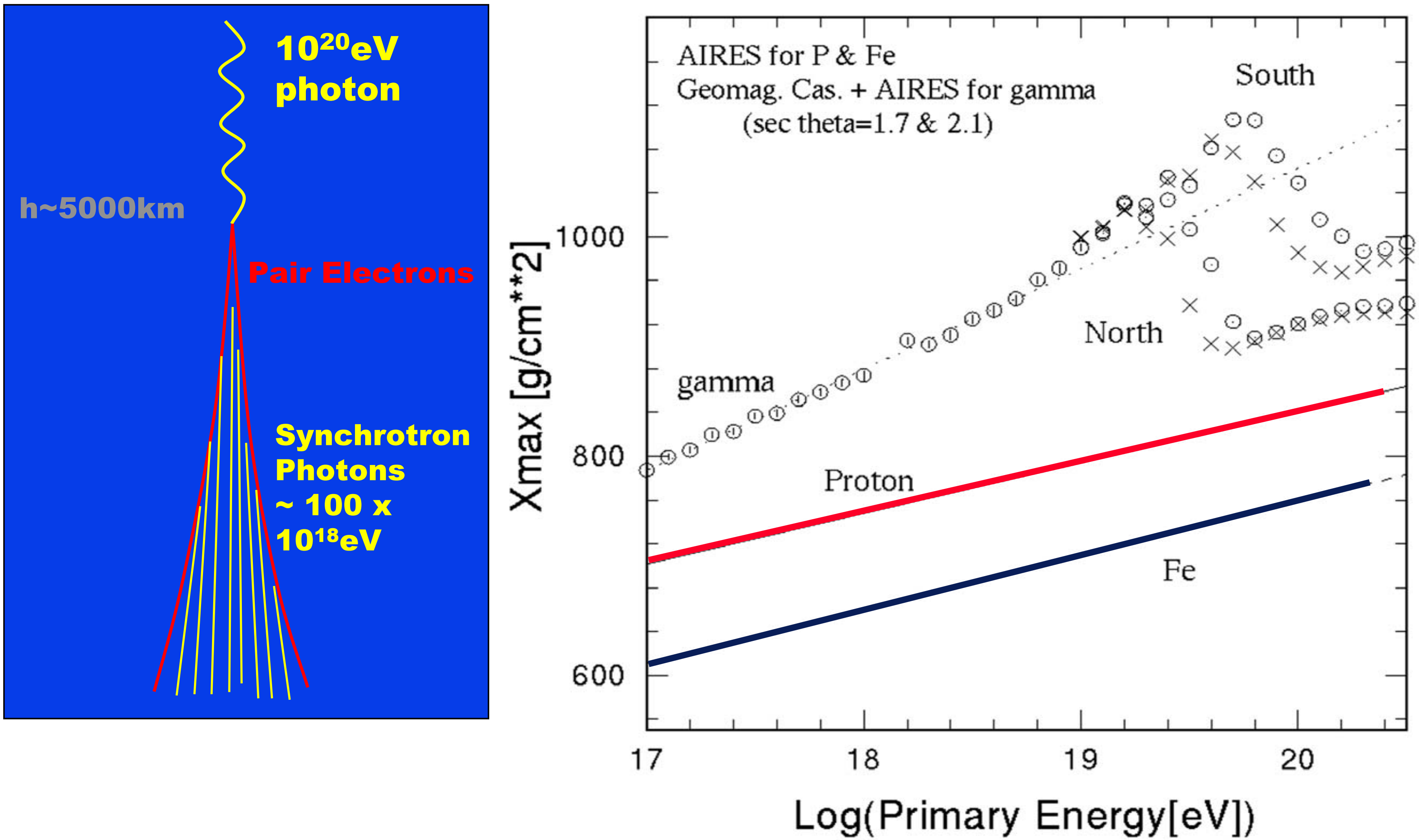
Neutrino error box is limited only by the EUSO angular resolution while the proton error box is dominated by the intergalactic magnetic field.

$\langle B \rangle = 1$ nGauss

$\langle d \rangle = 30$ Mpc



Identification of Gamma Rays and Nuclei



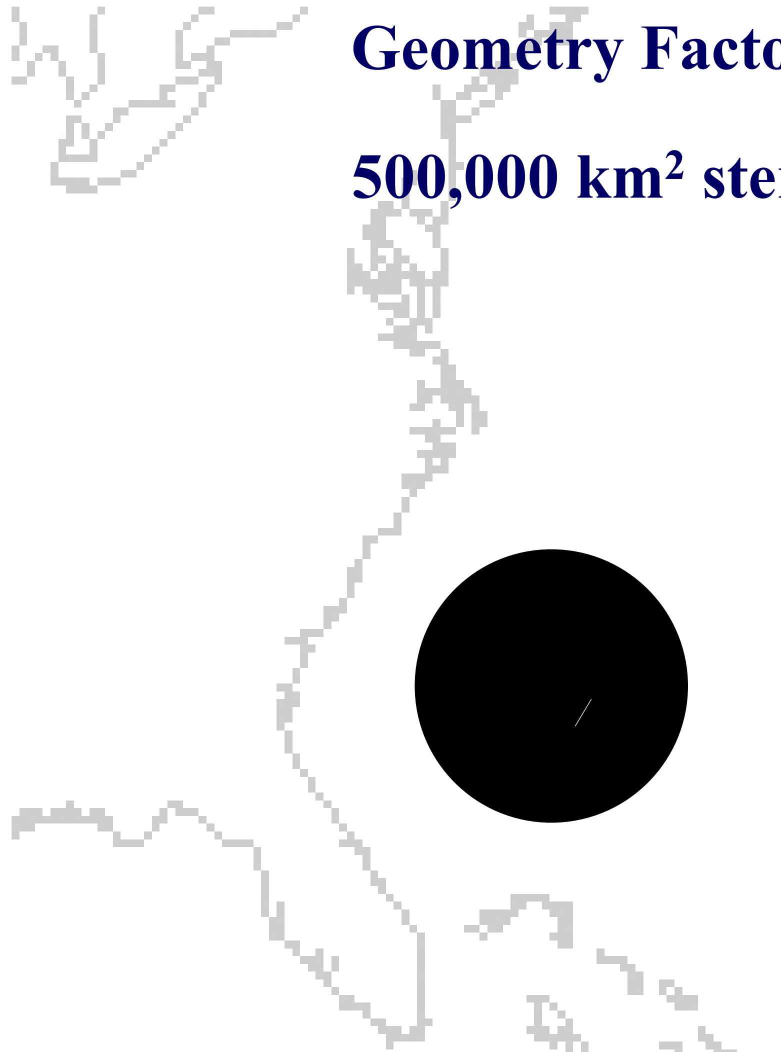
EUSO Operations

Duty Factor

- Contributors:
  - No manmade lights = 99.7%
  - In Umbra = 34%
  - low moonlight = 50-75%
- Total = 17- 25%

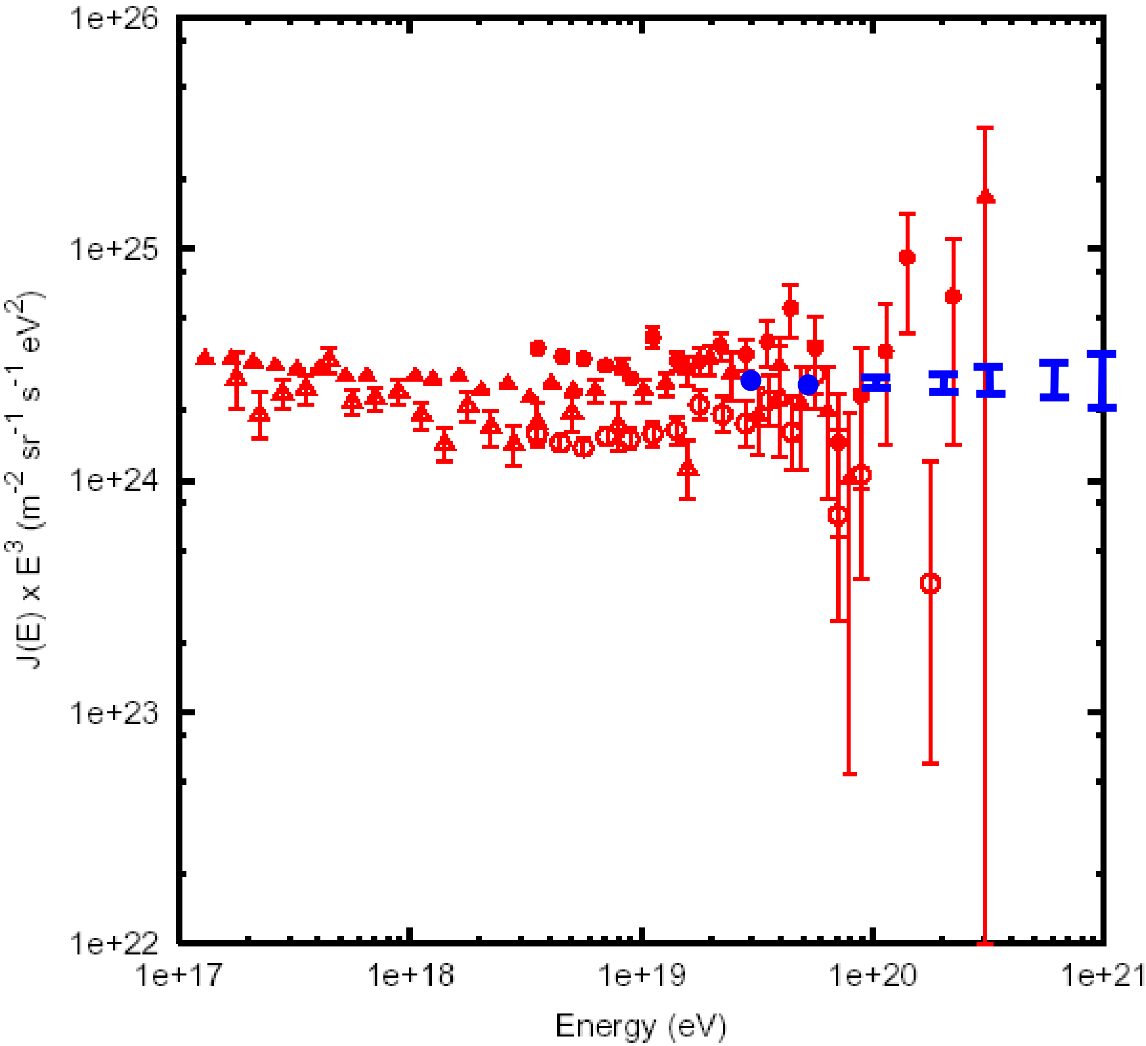
Geometry Factor

500,000 km^2 ster.



Most Important Science Result

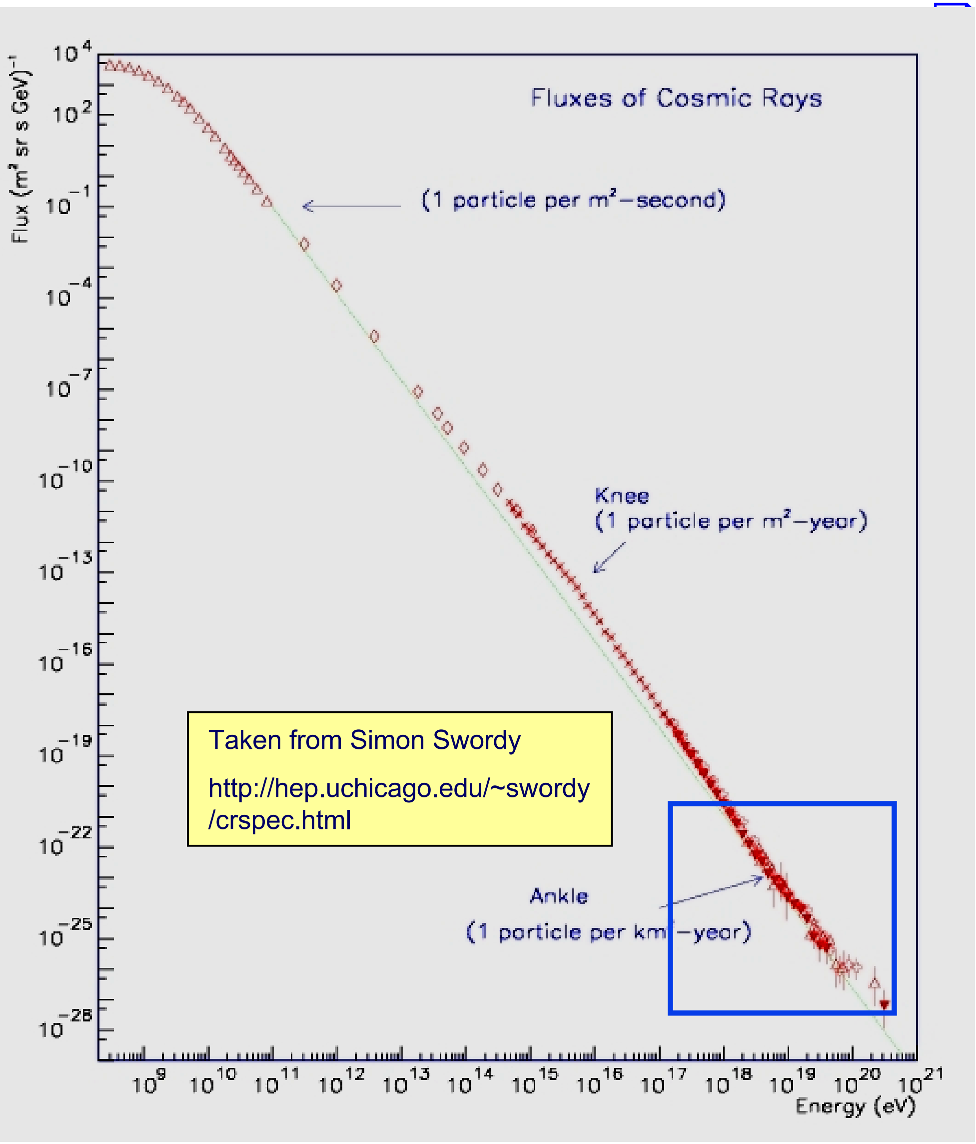
Investigate the Spectrum Beyond 10^{20} eV



Existing Data
Fly's Eye (triangles)
AGASA (filled circles)
HiRes (open circles)
[taken from Stecker, 2002]

Simulated EUSO data (blue)

These are Not Your Father's Cosmic Rays



Extragalactic Cosmic Rays ($>10^{18}$eV)

- **Larmor Radius**
  (Hillas, 1984)
- **No anisotropy toward the Galactic Center**
  (Hayashida H. et al., 1999)

GZK Cutoff ($>5X10^{19}$eV; >50 Mpc)

- **Protons produce Pions on the 3°K CMB**
  (Greisen K., 1966; Zatsepin G.T. & Kuzmin V.A., 1966)

Photodisintegration Cutoff ($>1X10^{20}$eV; >100 Mpc)

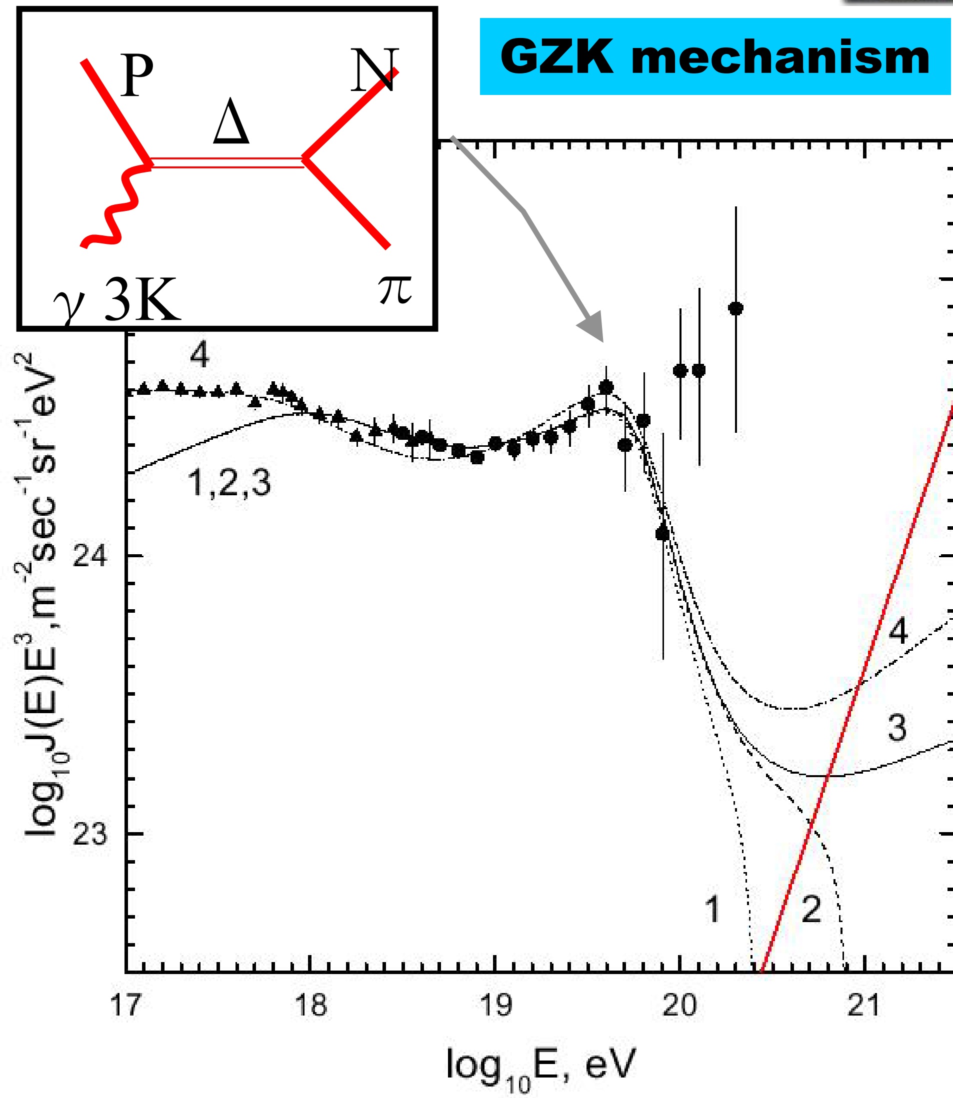
- **Photodisintegration of nuclei primarily on the 3°K CMB**
  (Stecker & Salamon, 1999)

GZK Proton Spectra

This Figure shows the four predictions for the EECR spectrum beyond 10^{20} eV taken from Berezinsky et al, 2002

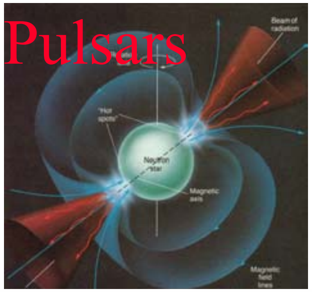
Notes: (1), (2), and (3) the source spectrum is assumed to be $E^{-2.7}$ and cosmological evolution is neglected. The three cases differ by the maximum source energy, E_{max}(in eV) = $2X10^{20}$, $1X10^{21}$, and ∞, respectively. (4) is for a source spectrum of $E^{-2.45}$, E_{max}= ∞, and cosmological evolution as $(1+z)^4$.

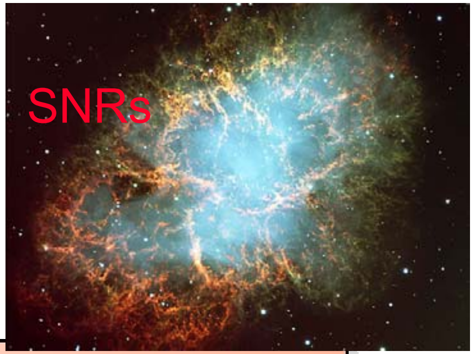
GZK mechanism

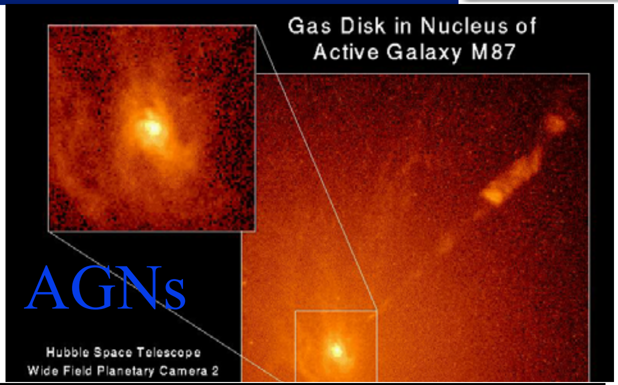


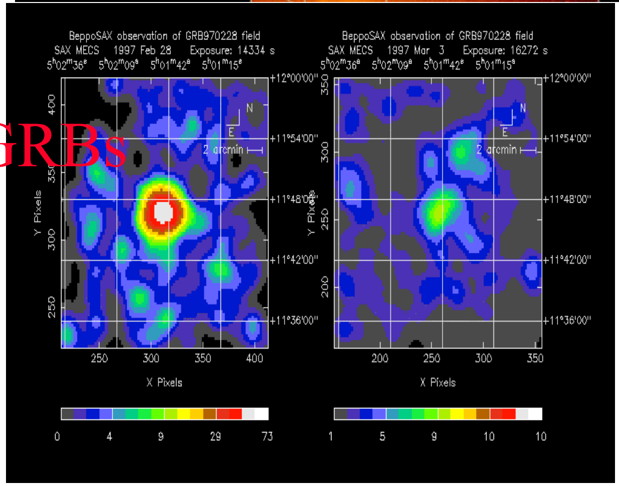
Note: Above 10^{20}eV the Universe is Transparent only to Neutrinos!

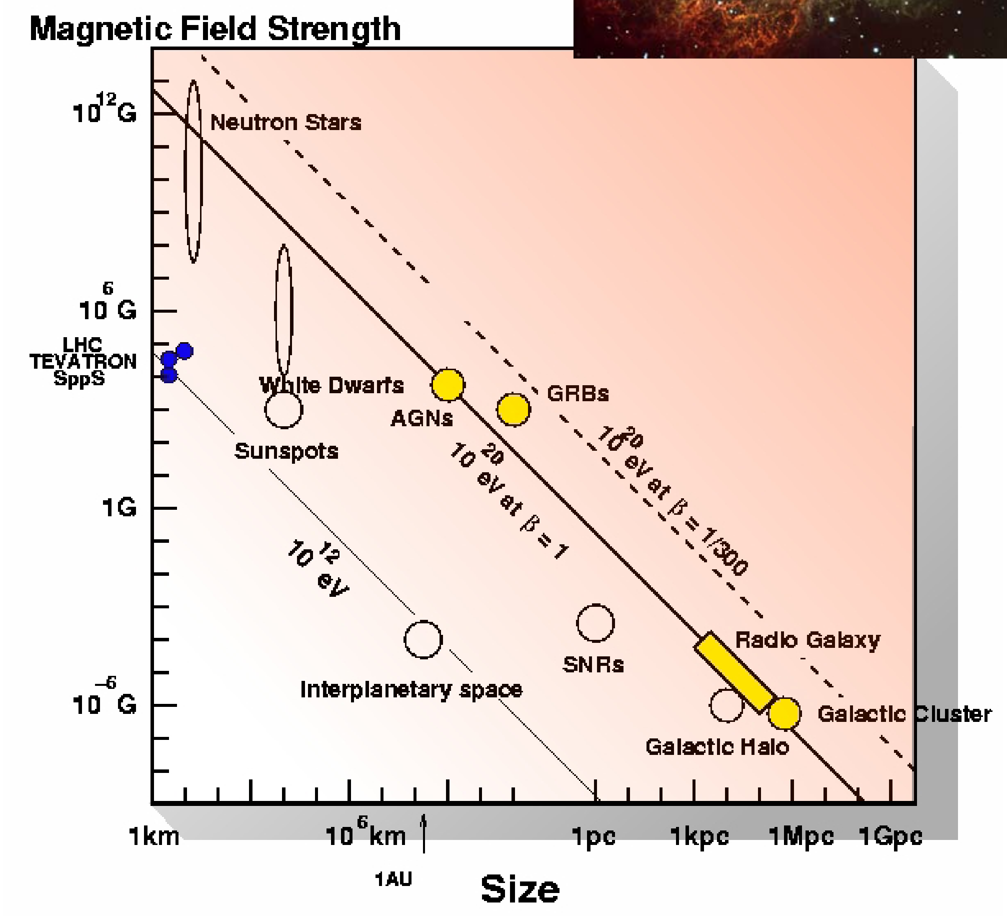
Bottom-up Candidates for the EECR Source

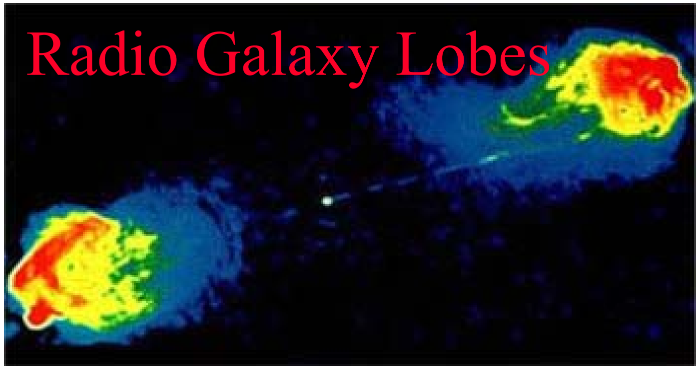












Top Down Candidates for the EECR Source (New Physics)

Hypothesis: Cosmic Rays at energies >10^{20}eV are the decay products of massive particles, e.g. Topological Defects , WIMPZILLAs, etc.

To recognize these, experiments must:

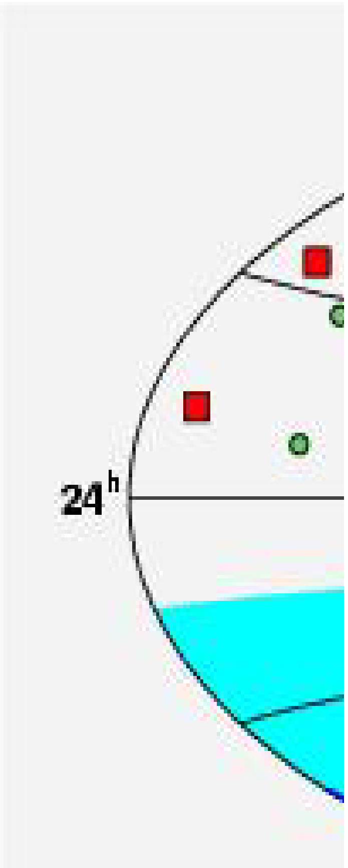
- ❑ **Measure the angular distribution**
- ❑ **Determine the nature of the incident particle, e.g. protons, nuclei, neutrinos, or gamma rays**
- ❑ **Measure the arrival time of the event**
- ❑ **Detect earth-skimming and upward showers**

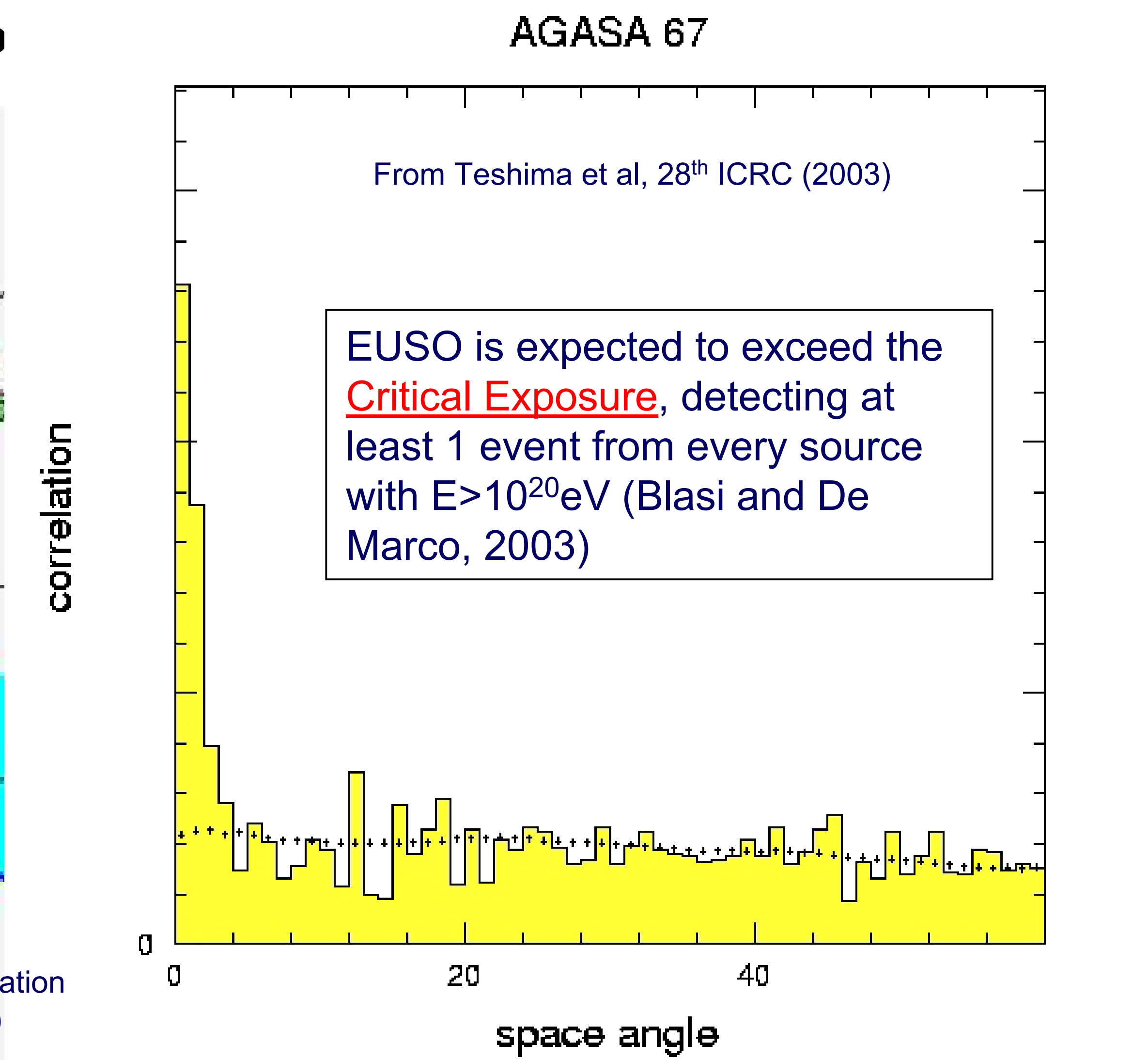
Arrival Direction Distribution >4×10^{19}eV zenith angle <50deg.

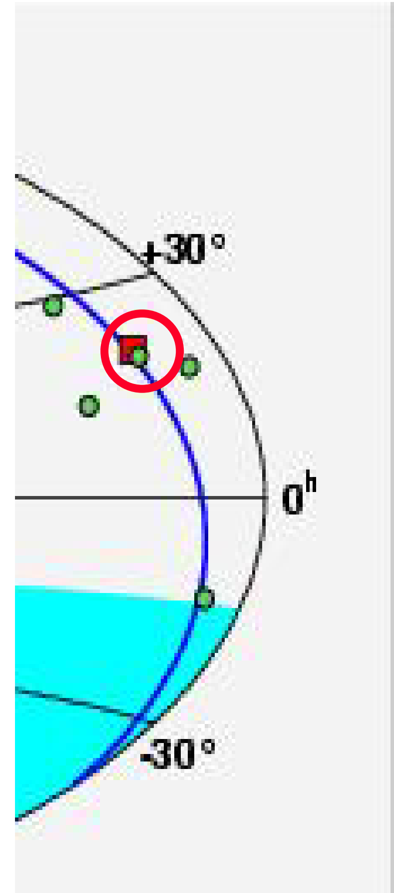
Isotropic in large scale → Extra-Galactic

But, Clust

- **1trip** **.)**

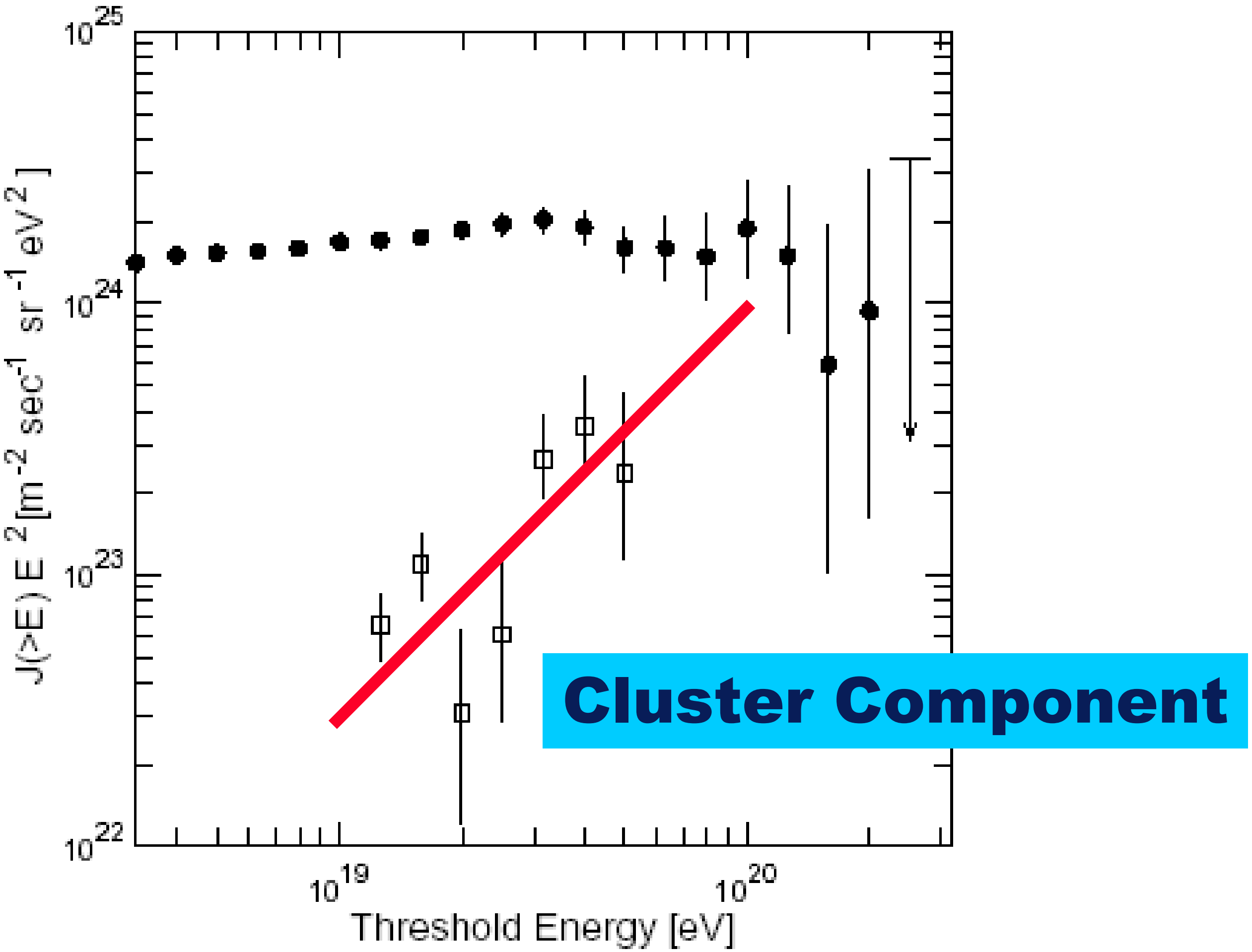






AGASA Collaboration
26th ICRC (1999)

Energy spectrum of Cluster events $\propto E^{-1.8+-0.5}$



Other New Physics

EECR measurements could reveal:

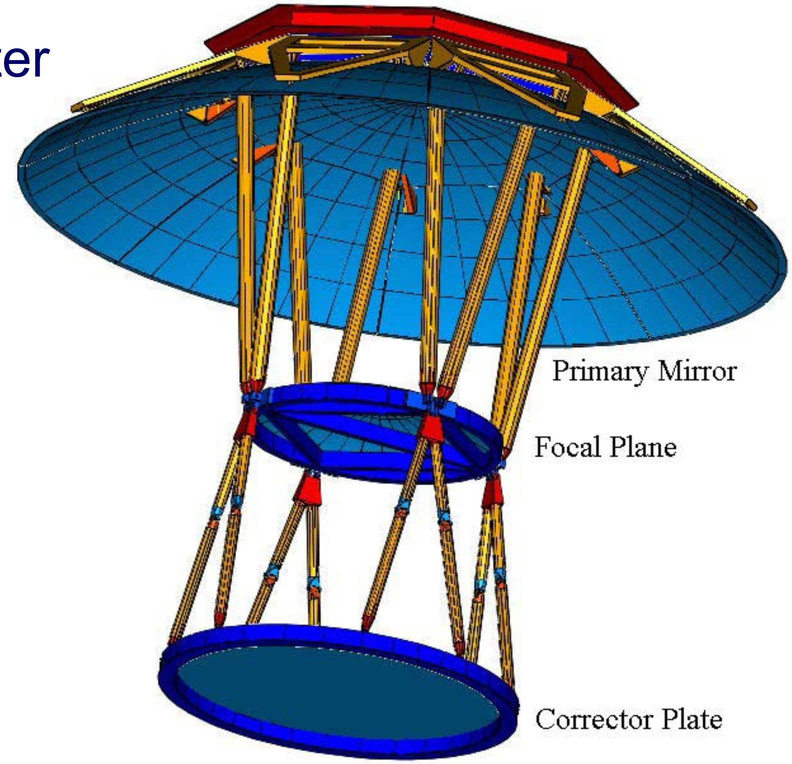
- The absence of the GZK effect for distant proton sources perhaps signaling a violation of Lorentz Invariance (Glashow, 2001 and others)
- Large neutrino cross sections perhaps signaling extra-dimensions in the Universe. (Kusenko and Weiler, 2002; Sigl, 2000 and others)
- Gamma rays from distant sources (e.g. GRBs with delayed high energy gamma rays), perhaps signaling quantum gravity effects (Kifume, 1999; Amelio-Camelia, 1998; Ellis, 1992).

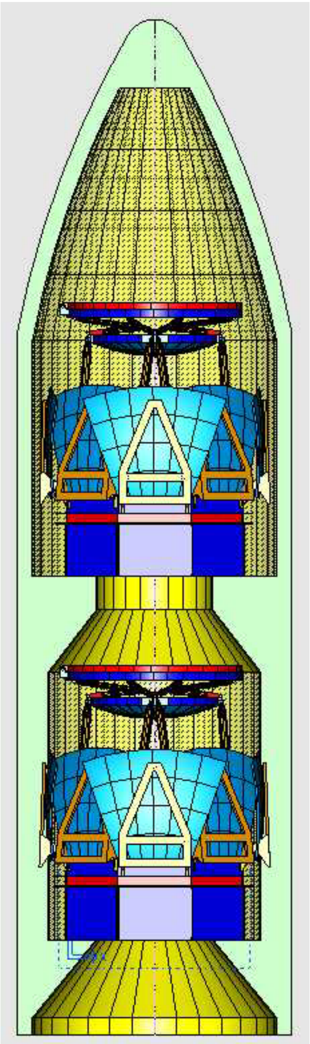
Truth Table

EUSO Test	GRB	AGN	TD	Wimpzillas	Z-Burst	$P\gamma_{2.7K}$ neutrinos	Quantum Gravity	LI Violation
Coincidence with GRB	X	-	-	-	-	-	-	-
$(N_\upsilon/N_p)>>1$	-	-	X	X	X	X	-	-
$(N_\gamma/N_p)>>1$	X	-	X	X	X	-	X	-
Anisotropy	-	-	-	X	X	-	-	-
Multiple events	X	X	-	-	X	-	-	X
Distant Point Sources	-	-	-	-	-	-	-	X
Nearby Point Sources	-	X	-	-	-	-	-	-
After GRB	-	-	-	-	-	-	X	-
Cutoff Energy	X	X	-	-	10^{20} eV/m_υ	X	X	-

Orbiting Wide Angle Light-collector (OWL)

- Two satellites flying in formation
- Angular Resolution: 0.2°
- Energy Resolution: 14%
- Aperture: $2X10^6$ km^2 ster
- Duty Cycle ~12%
- Eff. Aperture: $2.3X10^5$ km^2 ster
- http://owl.gsfc.nasa.gov





Conclusions

Extreme Energy Cosmic Ray Measurements from Space are Capable of:

- ❑ Following the Cosmic Ray Spectrum Beyond 10^{21}eV
- ❑ Distinguishing Neutrinos on an Event by Event Basis
- ❑ Distinguishing Protons, Nuclei and Gamma Rays on a Statistical Basis
- ❑ Measuring the Arrival Directions to ~±0.1°
- ❑ Measuring Earth-skimming and Upward-bound Cosmic Rays

<u>Making possible discoveries in Astrophysics, Cosmology and/or Fundamental Physics</u>

First EUSO Results expected ~2010!

BACKUP CHARTS

- Other Constraints on EECR Accelerators

Other Constraints on EECR Accelerators

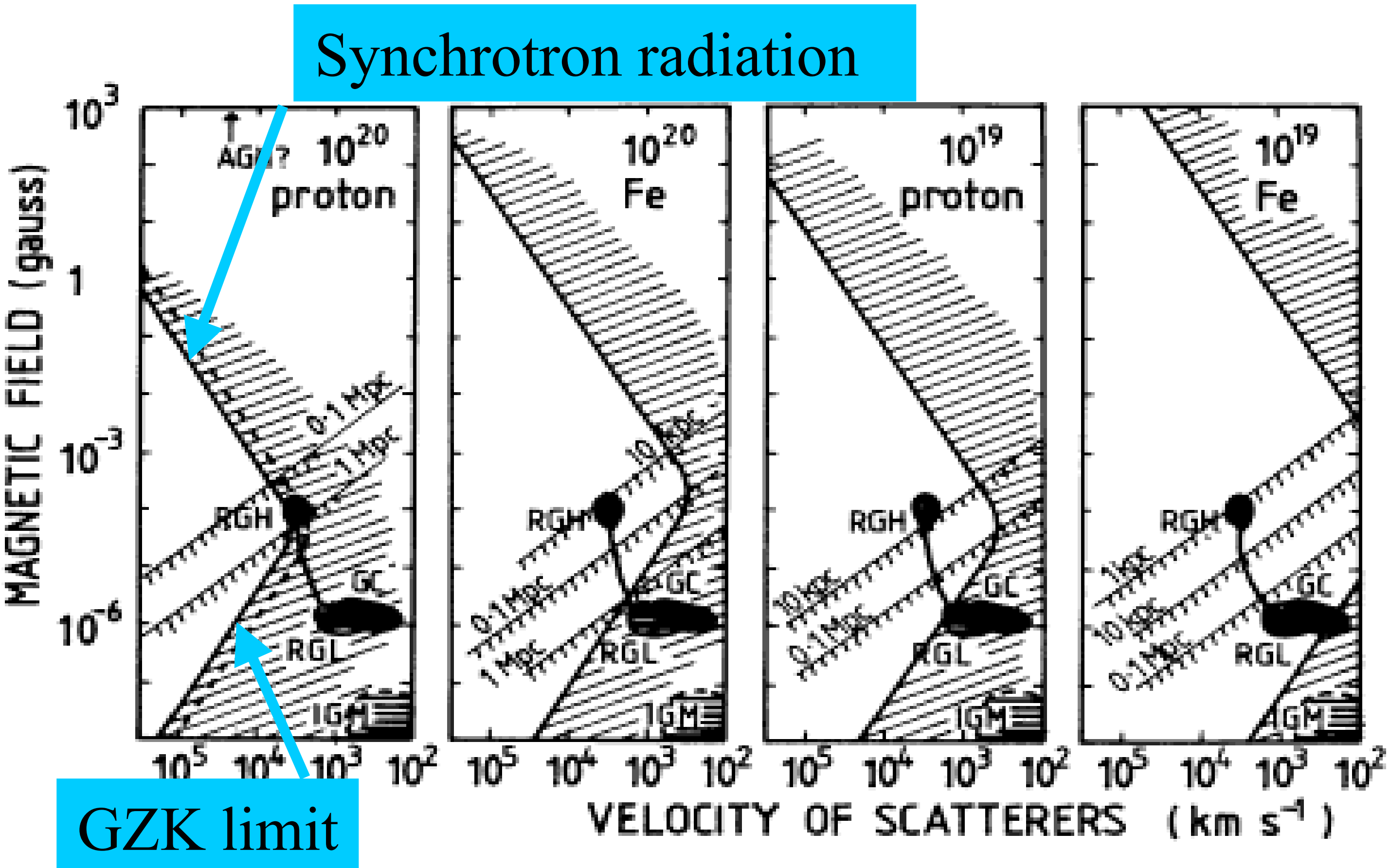


Figure 6 Combinations of magnetic field strength and velocity of scattering centers that allow Fermi acceleration to reach 10^{20} or 10^{19} eV for protons or for iron nuclei. Only the unshaded triangular region at the left in each diagram beats synchrotron losses (above the upper leg of the triangle) and photoreactions (below the lower leg). Any candidates must also lie above the diagonal line appropriate to their radius or diffusive escape will be too rapid. Positions of galactic clusters (GC), radio galaxy lobes (RGL), radio galaxy hotspots (RGH), and the intergalactic medium (IGM) are indicated.

Taken from (Hillas, 1984)